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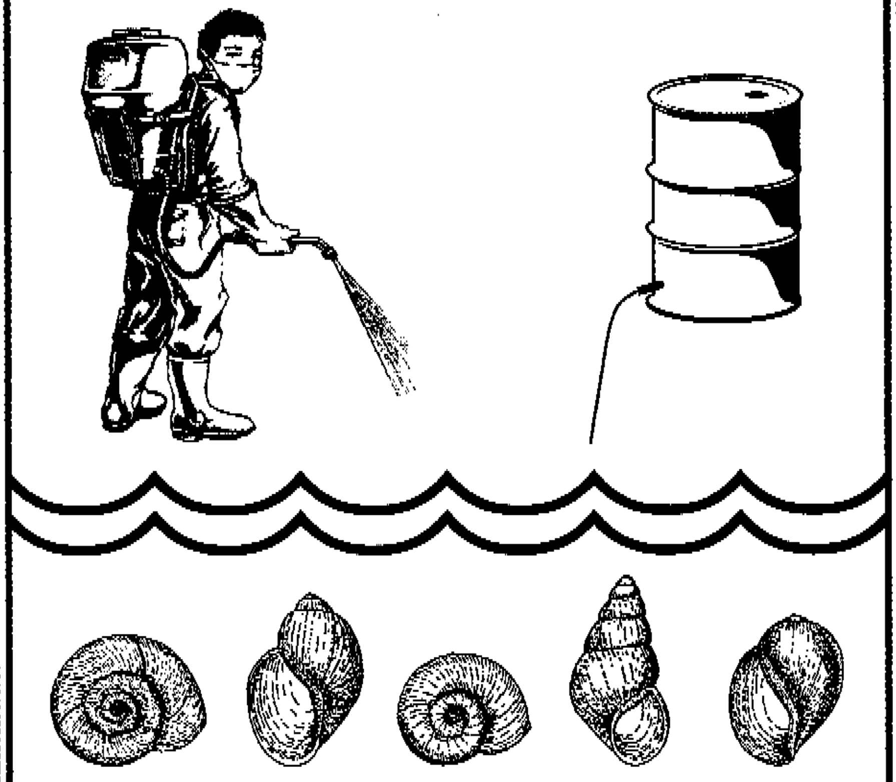

THE ROLE OF MOLLUSCICIDING IN SCHISTOSOMIASIS CONTROL

WORLD HEALTH ORGANIZATION

THE ROLE OF MOLLUSCICIDING IN SCHISTOSOMIASIS CONTROL

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CONTENTS

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1. INTRODUCTION

Schistosomiasis (Bilharziasis) is a complex, "person-made" helminth infection which affects around 200 million people in 74 tropical countries (Iarotski and Davis, 1981; WHO, 1985; Sleigh and Mott, 1986). Five schistosome species (*Schistosoma japonicum, S. mansoni, S. haematobium, S. intercalatum* and *S. mekongi*), taxonomically and epidemiologically distinct, and using one or more species of snail intermediate host, parasitize mankind; each has been described in considerable detail. The three former species are medically the most important; the latter two species are restricted in distribution to West-Central Africa and to the Mekong River in Southeast Asia respectively.

The latest report of a WHO Expert Committee on the Control of Schistosomiasis (WHO, 1985) gives detailed accounts of the epidemiology, pathology and methods of control of the disease. In addition, the report provides a brief review of progress in national schistosomiasis programmes and, perhaps most important of all, a strategy for morbidity control which aims at direct and rapid control of schistosomal **disease**, which is now distinctly feasible using integrated control procedures spearheaded by safe and effective chemotherapy. The concept that schistosomal disease may occur in only a proportion of the number of people infected is now generally accepted and can be expressed in simple terms as follows:

- **light** paired-worm load > low egg production > **little** pathology > **little** priority for control;
- **heavy** paired-worm load > **heavy** egg production > **marked** pathology > **high** priority for control.

While eradication of schistosomiasis is seldom attainable, the major objectives of current control programmes are directed *(i)* to reverse the trend towards heavy infections and *(ii)* to contain as far as possible the spread of the infection.

Until about a dozen years ago, snail host control, mainly by molluscicidiug (or by environmental alterations in the case of the amphibious *Oncomelania* snail hosts) was the key element in schistosomiasis control procedures. Numerous control projects in Brazil, Egypt, Ghana, Israel, Jordan, Madagascar, Philippines, St. Lucia, Tanzania, Venezuela, Zimbabwe and elsewhere, showed that snail control by molluscicides, usually in combination with other feasible methods, could, with careful planning and sustained organization, reduce or temporarily eliminate transmission. In the absence of satisfactory chemotherapy at that time, the development of snail control technology and approaches were then, not surprisingly, given greatest attention at both research and operational levels (Ansari, 1973). This emphasis, however, has recently been revised to make way for a new control strategy (WHO, 1985) as a result of:

- the availability today of new, safe and effective drugs capable of eliminating schistosomal morbidity through population-based chemotherapy campaigns;
- the recent development and ready availability of simple and quantitatively reliable diagnostic techniques;
- advances in the design of more relevant and cost-effective sanitary facilities and domestic water supplies;
- current rapid advances in data management mechanisms;
- efforts by many endemic countries to put primary health care principles into effect;
- increasing awareness that schistosomiasis is essentially a "person-made" disease and that affected communities must achieve a sense of responsibility aimed at significantly reducing transmission intensity;
- the fact that while no two transmission foci are similar, it is usually possible to predict major sites and seasons of transmission;
- realization that today most cases (probably more than 90%) of schistosomal **disease** are found in Africa where the requirements for sustained preventive health services are not infrequently deficient (see Annex 1);
- feasible national plans of action can be prepared, implemented and evaluated;
- the ready availability of bilateral and international collaboration on a long-term basis to help bring schistosomal disease under cost-effective control.

In contrast to these advances, the resources for snail host control per se have not markedly improved and the impetus to develop them has regressed in recent years. At the present time, only one chemical molluscicide is predominantly used in control programmes. However, endemic countries which have sufficient resources and sustained organizational capabilities and which place high priority on schistosomiasis control, do still undertake carefully planned molluscicidiug programmes either complementing or supplementing other control measures with very satisfactory results.

Nowadays, therefore, snail host control measures are best considered as one of several possible supportive procedures in integrated schistosomiasis morbidity control activities, dominated by population-based chemotherapy schedules. Bearing this in mind, the primary emphasis in the present document is more on practical aspects of the use of molluscicidiug in current schistosomiasis control programmes, rather than on theoretical considerations/research findings, especially since the latter have been adequately described elsewhere by Andrews, Thyssen and Lorke (1983); Ansari (1973); Cheng (1974); McCullough, Gayral, Duncan and Christie (1980) and others.

The feasibility/desirability of chemical snail control operations can probably best be considered within the three phases of schistosomiasis control operations defined in the WHO Expert Committee Report (WHO, 1985) as follows:

(i) **Phase 1 (planning)** is the period when the collection of necessary epidemiological data takes place, a national plan of action is prepared in which the quantitative goals of the control programme are defined according to the priority given to the problem, a feasible operational approach is decided upon, and appropriate resources are allocated to the programme.

(ii) **Phase 2 (attack/intervention)** is the period of active intervention. The operations are intensive and continually evaluated. In this phase a rapid reduction in prevalence and intensity of infection can be anticipated. This phase is usually shorter than the first phase. Preparations for phase 3 should be started at the beginning of phase 2.

(iii) **Phase 3 (maintenance)** is a protracted follow-up period during which maintenance measures will be necessary in most situations; fewer resources will be required and they will be used to support established facilities and primary health care for surveillance and monitoring.

2. OBJECTIVES OF SNAIL HOST CONTROL BY MOLLUSCICIDING

It is important to recognize that objectives should be defined as far as possible on a quantifiable basis and that they may vary not only from one endemic country to another, but also according to the ecological conditions of each transmission/snail habitat situation.

The main reasons for setting objectives are *(i)* to avoid an empirical, ad lib approach to the solution of problems, *(ii)* to assist in making valid evaluation of the programme and *(iii)* to improve the cost-effectiveness of control operations. While the definition of objectives is obviously essential in research studies, their inclusion in control programmes should never be regarded as superfluous.

The main objective of the use of molluscicides in schistosomiasis control programmes may be described as follows:

- to contribute, preferably in combination with chemotherapy and other feasible control measures, to significant reduction/control of schistosome transmission by cost-effective destruction of snail host populations and, in particular, infected snails in selected habitats and during the period(s) of peak transmission. The snail population density at transmission sites should be reduced by a minimum of 95% and this level of reduction should be maintained throughout the main season(s) of transmission.

Subsidiary objectives may include:

- destruction of snails in certain breeding sites which contribute significantly to augmenting snail host population density in nearby transmission foci; (good examples of this approach are noted in Morocco, St. Lucia, Tanzania (Ifakara), Tunisia, etc.);
- prevention of transmission at freshwater pleasure/tourist resorts (examples demonstrating the importance of this approach occur, or have occurred, at natural and man-made lakes/dams in Kenya, Rwanda, Zimbabwe and at waterfall pools in Tanzania, Mali, etc.);
- reinforcement of community involvement in control operations including awareness of where schistosomiasis is caught and how villagers can contribute to reduction/control of transmission by their own efforts, mainly by sustained behavioural change;
- marked reduction of intense transmission at sites used by workers at special risk (e.g. sites at fishing villages in Lake Volta, Ghana);
- elimination of a newly introduced potential snail host (e.g., *Biomphalaria straminea* in Hong Kong; spread of *Bulinus truncatus* and *Biomphalaria pfeifferi* in Ghana, etc.);
- total elimination of snail hosts to prevent the risk of transmission in certain kinds of habitats (e.g. some oases in northern Africa; certain small isolated transmission sites in Zanzibar, etc.); or
- preventing, as far as possible, the establishment of dense snail host populations in new irrigation schemes (e.g. Rahad irrigation scheme, Sudan).

3. GENERAL INFORMATION ON MOLLUSCICIDES

In the following nine sections, brief information is given on topics which have either direct or indirect relevance to molluscicidng operations and which may be useful to supervisors of chemical snail control programmes and also for training purposes.

3.1 Advantages/disadvantages of molluscicidng operations

Completely satisfactory statements on the advantages and/or disadvantages of molluscicidng operations are difficult to make as the parameters (e.g., transmission site characteristics, objectives, formulations, application procedures, staff training and resources) are likely to vary widely from one country to another and even for each transmission site. In general, however, among the advantages of selective molluscicidng operations are:

- rapid interruption of transmission can be obtained;
- community participation is not essential, but is desirable;
- cost efficiency can be very satisfactory;[b]
- application equipment is usually simple and cheap and can often be used for the control of other vectors;
- application methods are normally simple, do not require special skills and are easily learned (good supervision is, of course, essential);
- selection of important transmission sites (see Annex 2), where molluscicide application is

required, is usually simple and based mostly on water-use patterns;

- safety margins to man and his domestic animals and plants are very wide (toxicity to other non-target fauna and flora is temporary and does not cause concern, the regimen being focal and usually periodic);
- health education programmes are reinforced as a result of these operations;
- integration with other pesticide control programmes is usually easily arranged.

Among the disadvantages of mollusciciding are:

- the need for repeated applications, since eradication of snail host populations is rarely attainable;
- the sustained motivation, reliability and supervision of snail control teams, although mandatory, may not be assured;
- the effect on schistosomal morbidity, even when snail control measures are efficient and in the absence of chemotherapy, is delayed; and
- technical discernment is required for appropriate application procedures in the wide variety of transmission sites in any endemic area.

3.2 Characteristics of a suitable molluscicide

The perfect molluscicide does not yet exist and indeed may never do so. A list of characteristics has been laid down in a WHO publication (1965). The following minimum requirements apply:

- toxicity to snails at low concentration;
- they must be safe to use in respect of acute and chronic mammalian toxicity;
- if they enter the food chain, they must not produce adverse effects;
- they must be stable in storage for 18 months or longer;

Other considerations include acceptable cost; ready availability; particular specificity for snails; low toxicity for non-target biota; diversity of formulations; simple means of application; simple and reliable method of measuring concentration levels in habitats.

3.3 Currently available molluscicides

A vast array of compounds are molluscicidal. Duncan (1974) gives a good review of the development and application of molluscicides in schistosomiasis control. Among molecules given early consideration and long since abandoned are those of calcium and copper. Between 1946 and 1955 no less than 7000 chemicals were screened for promising molluscicidal activity (Ritchie, 1973) and sodium pentachlorophenate (NaPCP) was identified as potentially useful, but was later discarded as being too toxic; however, it is still being used in China. Similarly, several lead and tin compounds were observed to be highly active molluscicides , both in the laboratory and in limited field trials, but were not brought into general use because of serious reservations concerning their toxicity. In Japan, Yurimin (3,5-dibromo-4-hydroxy-4-nitroazobenzene) replaced NaPCP, but after being in use for a few years its manufacture ceased. Virtually the same fate applied to Frescon® (N-tritylmorpholine), one of the most highly active molluscicides (though not lethal to snail eggs) which failed to fulfil its early promise; though some stocks still exist for use in a few control schemes, they are unlikely to be replaced in the years ahead. Similarly, copper salts have been largely discarded in most snail control programmes. The molluscicidal efficacy of copper, irrespective of the method of application (in some slow-release matrices, in chemical barriers, in compounds of different anionic nature, etc.) has been less than satisfactory, especially in the presence of organic materials, certain kinds of dissolved solids, and at high pH values. Moreover, the cost-effectiveness of copper sulphate, in spite of its low purchase price, has been shown to be unacceptably high in comparison with that of niclosamide.

In Japan, an inexpensive compound named B-2 (sodium 2,5 dichloro-4-bromophenol) has been field tested in liquid and wettable powder formulations against the amphibious *Oncomelania nosophora* (Kajihara *et al.*, 1979). Its residual concentration in soil decreased rapidly and its uptake in rice did not exceed 0.03 mg/l. Its toxicity has limited its widespread use.

In the People's Republic of China, a search for new and more effective molluscicides of chemical and plant origin is being undertaken. Fluoracetamide and its analogues (bromoacetamide, chloracetamide) have been investigated against amphibious snails. These compounds have high molluscicidal activity, low toxicity for fish, are water soluble, stable and easy to apply. The results of small-scale field trials indicate that they are particularly suitable for use in fish ponds. Although these compounds can not be regarded as currently available, they are mentioned here because they have some promise of being effective in certain kinds of habitat.

Organotin compounds, particularly tributyltin oxide, showed promise as highly effective molluscicides with absence of significant mutagenic and carcinogenic effects. However, its effect on aquatic fauna, particularly shellfish has resulted in its being banned for use in marine paints in Europe.

At the present time niclosamide (marketed as

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[b] In recent years many references relating to schistosomiasis control state categorically that molluscicides are expensive and may lead to problems of toxicity to non-target organisms and deleterious long-term effects on the environment. This unqualified statement is misleading, if not indeed erroneous, when applied to focal/seasonal mollusciciding, particularly if it can be carried out using primary health care procedures. It did, however, apply to certain blanket or area-wide mollusciciding operations which were formerly practised mainly in countries with extensive, sophisticated irrigation networks. Klumpp and Chu (1987) have stated that in their experience in Iran, Egypt and Ghana, area-wide mollusciciding is expensive, wasteful, ecologically unsound and generally ineffective. They conclude, on the other hand, that focal mollusciciding is a cost-effective method in virtually all habitats. However, in endemic areas like the Nile delta, it is unlikely that even focal/seasonal mollusciciding will contribute significantly to a reduction in schistosomal transmission in the area as a whole. However, in certain affected communities where, for example, population-based chemotherapy campaigns may have proved less satisfactory, focal/seasonal mollusciciding, if carried out rigorously, could then probably play a useful, additional role in disease control.

Bayluscide®) is virtually the sole available molluscicide, and in terms of effectiveness and completeness of evaluation, it is the molluscicide of choice. It is also the only molluscicide, unlike numerous insecticides, which has been a commercial success. The usual formulations of Bayluscide® (70% wettable powder and 25% emulsifiable concentrate) are both highly effective. In practical use, a concentration of 0.6-1 mg/l is recommended with an exposure time of 8 hr (WHO, 1973), or 0.33 mg/l for 24 hr (Barnish and Prentice, 1981). The effective dose for amphibious snails (*Oncomelania* spp.) is 0.2 g/m^2 of moist soil. The manufacturer recommends 0.6 and 1 mg niclosamide/1 water of the wettable powder formulation for the mollusciciding of stagnant and flowing waters, respectively, while 0.4-0.6 and 0.6 mg/l, respectively, are recommended when the 25% emulsion concentrate formulation is used (Bayer AG, Technical Information; unpublished). The latter achieves an excellent spreading effect in standing water, with or without vegetation, when mixed with diesel oil at a ratio of 8.5 parts of 25% EC to 1.5 parts of diesel oil. The molluscicidally effective concentrations should persist for at least 8 hours. "Home-made" granule, sand and gelatin formulations have been applied with success in specific situations (see Andrews *et al.*, 1983). Niclosamide has also been commercially formulated in Egypt as a 60% wettable powder marketed as Mollutox®. Some characteristics of Bayluscide® and the source of supply are given in Annex 3; further details, if required, can also be provided by the manufacturers (Bayer AG). The most complete account of the biochemistry and toxicology of Bayluscide® is given in the review by Andrews *et al.* (1983); this document cites 322 references. At molluscicidal concentrations Bayluscide® is lethal to fish (unless, of course, they can escape to unaffected parts of the waterbody); fish, so killed, can be safely eaten. There is still no definitive evidence of resistance to niclosamide. Practical procedures for the field use of Bayluscide® are given in Annex 4. When used focally and/or seasonally, and in judicious combination with other control methods, the application of this molluscicide can be cost-effective and does not cause any serious adverse biocidal environmental impact.

3.4 Molluscicides of plant origin

During the present decade several important reviews on plant molluscicides have been published (Kloos and McCullough, 1982; Marston and Hostettmann, 1985; Mott, 1987). Research on plant molluscicides has also increased in recent years in the hope that they may prove to be cheaper, more readily available and more aligned to self-reliant control strategy, than the use of imported synthetic molluscicides. However, no plant molluscicide has yet been employed widely in any endemic country, nor can this prospect be readily envisaged in the next few years. The desirable characteristics of molluscicidal plants are shown in Annex 5 and the major classes of natural compounds with recognized molluscicidal activity, together with some plant species which produce them, are given in Annex 6. No plant molluscicide is specific to snails; some have been discovered because they are potent fish poisons. Few have been adequately tested under simulated field conditions. Long-term toxicological studies have not, as yet, been undertaken on any vegetable molluscicide, but obviously the same regulations apply in regard to their acute or chronic toxicology as do those for synthetic products.

Of the many plant species, belonging to at least 16 families, which show a notable level of molluscicidal activity, only a few can be short-listed as "candidate" plant molluscicides. Even for each of these "candidates" very serious caveats apply in regard to their general use; none can at present be recommended unreservedly.

No doubt, research on vegetable molluscicides will continue to gain support, but, from the viewpoint of their widespread availability and application in national control programmes, it seems too optimistic to expect any dramatic breakthrough in the years immediately ahead.

3.5 Mode of action of molluscicides

Research on the mode of action of molluscicides has followed two main paths. Firstly, the biochemistry and physiology of snails have been studied with the aim of explaining molluscicidal activity, or of demonstrating unusual features of molluscan metabolism or function which molluscicides might then exploit. While these seemingly logical approaches have not, as yet, led to the identification of any new agent, they have demonstrated other noteworthy relationships. Secondly, research on the bioassay of groups of related compounds has been undertaken with the aim of elucidating chemical structure-biological activity relationships. This approach has indicated some of the properties required of molluscicide molecules and has led, for example, to the discovery and development of niclosamide and nicotinanilide.

It has long been observed that poisoning with molluscicides causes the snail either to retract into the shell and expel haemolymph or to become swollen and remain extended from the shell opening. The latter response is seen particularly with organotins and certain carbamates and suggests loss of water-balance control. The water-balance of gastropods is thought to be under neurosecretory control. N-tritylmorpholine has been shown to reduce neurosecretory activity in *B. truncatus*, while long-term exposure of the pulmonate, *Indoplanorbis exustus*, to barium chloride and copper sulphate also resulted in diminished neurosecretory activity. In addition, it has been shown that water flux through *B. glabrata* falls in the presence of a number of molluscicides at concentrations around their LC_{50} values. It may well be, therefore, that molluscicides cause stress on the water-balance system and that this alone is lethal to the snail, or that reduction of normal water flow through the snail precipitates other disturbances in metabolism or physiological function similar to those described above. It is of interest that the activity of some insecticides has been attributed to such multicomponent poisoning, caused by the release of neurohormones.

3.6 Toxicity, mutagenicity and carcinogenicity testing

While many available and candidate molluscicides have undergone adequate short– and medium–term (90 days) toxicity testing, few have been subjected to long–term toxicological studies. There is no strict correlation between acute toxicity and carcinogenicity (e.g., a chemical with high acute toxicity may be of low carcinogenicity or vice versa). According to the available literature niclosamide is the only molluscicide which has undergone rigorous carcinogenicity testing (Andrews *et al.*, 1983).

In regard to mutagenicity testing, the growing empirical relationship between mutagenicity and carcinogenicity does not imply that the two processes are identical, but mutagenicity testing does suggest itself as a rapid pre–screening assay for carcinogenicity. With this reservation in mind, it is of interest that when N–tritylmorpholine, copper sulphate and sodium pentachlorophenate were recently tested for mutagenic properties in a bacterial system, none showed any evidence of mutagenic activity.

3.7 Resistance to molluscicides

Fortunately, from the practical viewpoint, there is still little evidence that snail hosts can develop serious resistance to molluscicides, nor has this phenomenon yet hampered snail control operations. For diverse reasons, resistance to molluscicides will probably never attain the same socio–economic importance as the problems arising from resistance to insecticides. Observations in the literature on this topic can be summarized as follows. Preliminary and debatable evidence has been reported from foci in Iran indicating increased resistance of *Bulinus truncatus* that had been subject, for about 10 years, to an annual treatment with niclosamide at a concentration of 1.0 mg/l (Jelnes, 1977). Moreover, field populations of *B. truncatus* exposed to N–tritylmorpholine in Sudan have been shown to be more tolerant to the chemical and to take it up more slowly than snails from untreated areas (Daffalla and Duncan, 1979). In St Lucia, *Biomphalaria glabrata* exposed to niclosamide at regular intervals for 9 years did not exhibit any evidence of resistance; indeed their susceptibility to Bayluscide® was similar to *B. glabrata* from other habitats in St Lucia which had never been exposed to mollusciciding (Barnish and Prentice, 1981).

In laboratory studies some success has been claimed to produce selected strains of planorbids with increased tolerance to molluscicides (Newton, 1963; Sullivan *et al.*, 1984; Jelnes, 1987).

With regard to the amphibious *Oncomelania* snail hosts, several studies have been undertaken by Japanese workers on resistance to molluscicides, mainly sodium pentachlorophenate (NaPCP). The results have been inconsistent, some providing evidence of resistance, while others have not done so, even among snail populations treated with NaPCP twice a year for more than 18 years.

An attempt was made to develop a prototype molluscicide resistance test kit for use in the field. This kit was sent for evaluation to a dozen specialists working in endemic areas where sustained chemical control of snail host populations was being practised; unfortunately, definitive evaluation of the kit has not materialized due to a poor response rate.

3.8 Laboratory screening of molluscicides

In 1965, the World Health Organization (1965b) supported the preparation and publication of guidelines for the screening and evaluation of molluscicides. The methods and recommendations established at that time remain valid today. Later, in 1970, the Organization convened a meeting to review in depth molluscicide testing and evaluation (WHO 1971). The report of that meeting, among other subjects, describes in considerable detail preliminary, definitive and comprehensive laboratory screening procedures for both aquatic and amphibious snail hosts. Duncan and Sturrock (1983) have described the laboratory screening of plant molluscicides.

3.9 Field testing and evaluation of molluscicides

In the mimeographed report (WHO 1971) pertinent information is given on the following topics: testing sites; objectives; main parameters governing field testing; mode of action and formulation of the molluscicide; factors influencing transmission; patterns of chemical dispersal in different types of transmission site; the use of chemical estimation; bioassay procedures; auxiliary methods (dyes and tracers); the interpretation of snail host reinfestation after treatment. The field testing of plant molluscicides has recently been described by Sturrock and Duncan (1983).

4. THE APPLICATION OF MOLLUSCICIDES

4.1 Some general aspects

Mollusciciding operations have been and remain today the most important method for the destruction of snail hosts, especially the truly aquatic, planorbid species belonging to the genera *Bulinus* and *Biomphalaria*. *Oncomelania* spp., which transmit *S. japonicum* in the Far East, are on the other hand less amenable to chemical control in most ecological situations. *Oncomelania*, in contrast to the planorbid genera, are amphibious, dioecious, operculate, very small and reproduce relatively slowly. Environmental alterations are often more successful than molluscicides to control these prosobranch snail hosts and, in addition, such modifications frequently provide other benefits for socio–economic development. Nevertheless, mollusciciding with niclosamide and other compounds (e.g. sodium pentachlorophenate and some amides) are still selectively employed in China, the Philippines and in the Lindu Valley, Sulawesi, Indonesia, especially where other procedures such as drainage, filling-in, flooding, etc. cannot be implemented.

Mollusciciding is not a feasible method to control *Tricula* spp., which transmit *S. mekongi* in certain locations in the huge Mekong river, nor is it cost-effective in certain endemic zones (mainly mountainous areas and flood plains) in China.

In general, and from a practical viewpoint, snail hosts of the aquatic genera *Bulinus* and *Biomphalaria* are almost equally susceptible to the available molluscicides. Moreover, both genera occur in a wide variety of freshwater habitats including lakes, dams, rivers, streams, ponds, borrow pits and irrigation systems. Both are extraordinarily adaptable to different ecological conditions and their population densities can fluctuate widely according to seasonal changes and other impinging factors. Both can be present in the same habitat, but one species is usually dominant. Precise knowledge of the interaction of the numerous factors, which govern the survival/regression of snail host populations, is still lacking, but it seems that both *Biomphalaria* and *Bulinus* tend to prefer more stable waterbodies. On the other hand, unstable or changing transmission sites, where snail population densities increase rapidly during favourable conditions and where human contamination is high, must be kept under regular surveillance. The recent ascendancy of *Biomphalaria* in the Nile delta, where concomitantly *Bulinus* has declined, is notable. Similarly, in the Volta river below the Akosombo dam site, *Biomphalaria* snails and *S. mansoni* were formerly quite rare; nowadays following the ecological changes brought about by the barrage of the river, *Biomphalaria* snails are abundant and intestinal schistosomiasis is a major public health problem in many communities. The ease with which these truly aquatic snails can rapidly spread to new, isolated habitats raises intriguing questions.

The distribution of the snail hosts in their habitats is non-random, reflecting the whereabouts of the food resources (e.g. decaying vegetation, algae) and also physical features (e.g. sandy/muddy substratum, water flow patterns) which attract or repulse the molluscs. Snail host populations thus tend to be dynamic in space and time. These principles and the observations that low infection rates (e.g. less than 1.0%) in snails may be associated with relatively high infection rates in the local human community, point to the need *(i)* to identify potential transmission sites, both geographically and seasonally, and *(ii)* to predict the habitats favoured by the snails, if cost-effective mollusciciding is to be successfully carried out.

With relevance to each endemic country among the main parameters governing whether snail host control operations should or should not be carried out, the following determinants may be listed:

- the objectives and phasing of the schistosomiasis control programme;
- the intensity and seasonality of transmission;
- the location and characteristics of the transmission site;
- the resources and maintenance of manpower, equipment and finance.

It may also not be superfluous to repeat and stress the following views:

- Experience has repeatedly demonstrated that molluscicides can significantly reduce snail host populations, but seldom eradicate them. Repeated applications are therefore necessary in order to prevent intense transmission.
- The real objective of mollusciciding, as with other control tools, is to help reduce/prevent schistosome morbidity and not necessarily to destroy **all** snail populations, many of which are unlikely to contribute significantly to schistosomal disease. Moreover, it is "man" who is the "vector" of *Schistosoma* spp.; the snails are innocent. Mollusciciding operations at each transmission focus, if they are to be undertaken, need to be carefully planned and implemented by well motivated, multidisciplinary teams.[c] Otherwise, they are likely to be simply wasteful.
- Mollusciciding involves the treatment of water, not snails. Thus cost-effective treatment involves attaining a standard concentration of the chosen chemical in a given volume of water usually over a specified period of time, irrespective of the number of potential snail hosts present in the waterbody.
- Mollusciciding involves mastery of certain simple techniques allied to sound experience of field transmission patterns. Advanced diplomas are unnecessary for this type of work, but good organization and the traits of loyalty, common sense and conscientiousness are mandatory.

There is now greater appreciation than even before that snail host control activities usually form part of a broad range of transmission site control operations including, for example, those which will ensure favourable modifications of human water-contact and contamination behaviour (see Annex 2). Thus identification of the most important potential transmission sites and prediction of the main seasons of transmission are crucial initial tasks. Next, if snail control activities are to be initiated, careful consideration must be given to the basic options of desirability and/or feasibility. In many endemic areas, snail control by mollusciciding may be desirable, but not feasible as the organizational infrastructure is not locally available to implement it on a sustained, recurrent basis. In other areas, mollusciciding may be feasible, but not desirable since the intensity of infection is insufficient to cause significant morbidity. Thus both options must be met.

As part of the current strategies for schistosomiasis morbidity control it becomes

[c] The members of such teams should be able to contribute to all aspects of schistosomiasis control (diagnosis, health education, water supply and sanitation, chemotherapy) as well as the surveillance and control of other communicable diseases such as malaria, dracunculiasis, onchocerciasis, etc.

increasingly evident that potential snail host control operations must nowadays be intimately associated, more than ever before, with public health considerations (e.g. priority rating, based on quantitative criteria, for undertaking control operations) and subsequently with the implementation of population-based chemotherapy schedules. In general, it is unwarranted to undertake snail control operations in areas where there is no evidence that schistosome infection is giving rise to detectable morbidity. However, if elimination of transmission is the principal objective, which is the case in such countries as Algeria, Jordan, Tunisia, etc., then snail control by mollusciciding may be obligatory in biotopes of high risk. In addition, in areas of intense transmission, where chemotherapy is being applied, it is usually desirable that snail control activities will be closely coordinated with the treatment regimen. In particular, snail host control activities, like other elements in morbidity control operations, must make a discernible contribution to reduce schistosomal transmission to levels which no longer give rise to significant disease in the affected population.

Similarly, if snail control operations are not excluded by the options of desirability/feasibility, then plans for their implementation must incorporate satisfactory solutions to the following queries: where, when, how and by whom to implement them? In addition, items such as the aims, costs and evaluation of results must be included in the provisional plans of action and later in the national schistosomiasis control manual which are now being prepared for planning and training purposes in an increasing number of endemic countries (e.g. Botswana, Brazil, Cameroon, Malawi, Morocco, etc.).

While the primacy of chemotherapy among current approaches to schistosomiasis control is emphasized, the other more ecological intervention measures, for a variety of reasons, should never be neglected or given only tacit acknowledgment. Chemotherapy can achieve remarkable reductions in prevalence in many endemic areas. However, to sustain this achievement other interventions are necessary. Accordingly, inclusion of snail host control measures can best be ensured only if they are shown to be cost-effective. Similarly, training courses on schistosomiasis morbidity control should always include the non-human elements in the cycle of transmission. Fortunately, the policy of the World Health Organization in regard to schistosomiasis morbidity control and training programmes continues to be catholic and embraces, as far as possible, all components (e.g., chemotherapy, snail host destruction, environmental improvements, health education, etc) which are likely to provide cost-effective, sustained results.

4.2 Where to apply molluscicides?

Formerly, mollusciciding operations were carried out according to two broad strategies *(i)* focal/seasonal and/or *(ii)* blanket (= area wide) applications. At the present time, the latter approach is rarely advocated as it is usually too costly, and environmentally unsound (see footnote 1). On the other hand, since schistosomiasis transmission in almost all endemic foci is spatio-temporal in pattern, focal/seasonal mollusciciding operations are likely to be the rule rather than the exception. Such selective mollusciciding applications are usually restricted only to those places much used by the populace for such purposes as swimming, bathing, washing, etc. and to nearby habitats which may act as snail host repositories. The former sites are known to the local people and are easily verified by evidence of frequent access. Simple maps showing the location of transmission sites should be prepared and kept up to date. Such maps should also correlate with prevalence rates in the local human population, as mollusciciding should normally not be undertaken at sites with insignificant infection. Drinking-water places are usually separate and are generally not important as transmission sites. Many large rivers (e.g. Congo, Gambia, Zambezi) are not in themselves important in transmission, but the construction of dams, across both large and small river systems, usually leads to ecological changes favouring transmission. Most snail hosts are found on preferred types of aquatic vegetation (e.g. water lilies) especially if not too dense, so special attention should be given to such microhabitats in the transmission site.

In irrigation schemes transmission is usually most intense close to human habitations where water contact and contamination are both frequent. The places and periods of transmission are likely to vary from one scheme to another, but they can usually be identified by experienced personnel if carefully conducted field surveys are undertaken (see Annex 2).

In still waterbodies the molluscicide should be applied as a general rule to a radius of at least 15 metres around the transmission site. It may also be necessary to remove dense aquatic vegetation to permit improved penetration of the molluscicide. In flowing-water habitats the mollusciciding procedures are a little more complicated than in standing-water sites. Simple solution dispensers, which can be made locally may be required and should be sited just upstream of the main water contact places (see Annex 4).

4.3 When to apply molluscicides?

The concept of seasonality of transmission may require some elaboration. For example, in a few endemic areas it may not be possible to predict precisely a period of the year when the level of transmission is so light as to be unimportant; the periodicity of mollusciciding should therefore correspond to this relatively unusual situation. In the majority of areas, however, most transmission will be restricted to certain seasons which promote increased human water contact, snail host population density and schistosomal development, all of which are likely to contribute to the severity of disease in the local community. Thus the application(s) of molluscicide should be geared to such seasons with the main aim of reducing peak transmission levels to relatively innocuous proportions.

The main transmission seasons are usually determined by rainfall and temperature patterns. Flooding, drought and low temperatures (below 18°C) tend to depress/interrupt transmission. On the other hand, drought may bring about increased transmission by accentuating human contact at certain sites. Molluscicidiing programmes should therefore take due account of these natural climatic features and their consequences.

In some endemic areas transmission may occur to a greater or less degree for nine or more months of the year.

Most transmission in both equatorial and tropical zones takes place in the early and mid-main dry season. In Central-West Africa (Congo, Gabon, Cabinda, etc.), however, the main transmission reason is still undetermined. Secondary transmission may occur during the "small" dry season, if one exists.

When transmission is seasonal a minimum of three applications of molluscicide is usually required annually as follows:

- first application towards end of main rainy season after flooding has ceased;
- second application about six weeks later during early dry season;
- third application at the start of the "small" dry season.

More frequent applications may be needed when the transfer of infection is "continuous" (e.g., certain areas in Zaire) or if snail hosts belonging to the *forskalii* group are responsible for transmission (e.g., in The Gambia, Cameroon, Gabon, Mauritius, Madagascar, Niger, Nigeria).

In small, still waterbodies (e.g. ponds, borrow-pits, small dams) molluscicidiing is most effective when they are relatively full. When these habitats have almost dried out molluscicidiing is then usually inappropriate.

The timing of molluscicidiing should also be linked to the delivery of population-based chemotherapy, and preferably should precede the latter if chemotherapy is undertaken during periods of intense transmission.

In summary, it will now be evident that the timing of molluscicidiing applications should be determined by local rainfall, temperature, water-use and snail host population density patterns and also, not least, by population-based chemotherapy programmes. Decision-making will be a matter of simple observation and common sense.

4.4 How and by whom should molluscicides be applied?

Some guidelines on how to apply the reference molluscicide, Bayluscide®, are given in Annex 4. A detailed description on the use of molluscicides is provided in the WHO publication "Snail Control in the Prevention of Bilharziasis" (WHO 1965b). The manufacturers of Bayluscide®, Bayer AG, will also provide instructions on request.

For practical purposes the techniques of molluscicide application are not difficult. For all habitats a simple calculation must be made to determine water volume and also, if necessary, flow-rate in order to calculate the dosage (concentration x time, ct product) required (see Annex 4). Except in the rare foci where large quantities of molluscicide are required, great precision is not needed for the vast majority of habitats.

Apart from the usual wettable powder and liquid (emulsifiable concentrate) formulations, some available and candidate molluscicides have been incorporated in various slow-release matrices (see Cardarelli, 1974). The term "slow-release" may be defined as the continuous, long-term release of a chemical agent, usually at sublethal concentrations, from a matrix for a period of time ranging from months to several years. The attractions of this approach are purported to include reduced costs, greater operational simplicity, long-term destruction of free-swimming larval stages of *Schistosoma*, particular efficacy in small, static waterbodies and increased environmental safety (the latter may not prove to be true in the case of organotin and organolead candidate molluscicides). In experimental field testing of molluscicides in certain slow-release preparations the results have been encouraging (DeSouza and Paulini, 1969; Prentice, 1970; Prentice and Barnish, 1980; Magendantz, 1974; Upatham and Sturrock, 1977; and others), but further studies are desirable before any definitive recommendations can be made for their use in routine control operations. Slow-release formulations are unlikely to be effective in snail habitats characterized by flowing water, marked water-level fluctuations, severe wind and wave action, silt deposition and substrate instability.

The main requirements of molluscicidiing include: molluscicide; sprayers (see Annex 7), buckets; simple weighing apparatus; tape measure and plumb line; record forms; field uniforms, including Wellington boots; transport and fuel.

A molluscicidiing team usually consists of three people: a field technician/supervisor and two labourers. Minor tasks, such as maintenance of equipment, may be allocated to the driver. Such staff must be thoroughly trained and multidisciplinary (see footnote 3); they should receive incentives for arduous field work (see Annex 1).

Molluscicidiing operations may also be carried out by primary health care personnel who have received basic training on schistosomiasis epidemiology and control. In addition, as schistosomiasis is undeniably a "person-made" disease, the role of the local community in carrying out snail control operations deserves to be carefully considered; this is particularly desirable where transmission sites are well defined, relatively few in number and close to the village or town, and also where there is good community structure and discipline to promote self-reliance in terms of health and socio-economic development.

5. EVALUATION OF MOLLUSCICIDING OPERATIONS

Formerly, when very large quantities of niclosamide were applied as "blanket treatments" (such treatments are now seldom, if ever, undertaken), it was necessary to use the molluscicide as economically as possible. For this purpose reliable analytical methods to record the concentration of the molecule (2', 5-dichloro-4'-nitrosalicylanilide) in the irrigation system or natural waterbodies were then obviously important. Several relatively simple field tests for the determination of niclosamide concentration were developed by Strufe (1962 and 1963) and Dawson *et al.*, (1978). Such field tests are, of course, also useful for research studies, but they are seldom needed for focal mollusciciding operations where only small quantities of the chemical are periodically applied.

From the practical viewpoint, the effectiveness of mollusciciding operations can be assessed by a number of methods; only two of them will be briefly described below.

(i) Effect of molluscicide on caged snails

Just prior to mollusciciding, local snail hosts are collected and placed in nylon-mesh cages (overcrowding should be avoided[d] and a few leaves of aquatic plants may be added) which are then secured at various places in the transmission site to be treated. For control purposes, the same number and species of snails are put in similar cages and placed in a nearby untreated site. At 24 hours following mollusciciding the mortality rates in the treated and control groups are compared. It is expected that in the treated area all caged snails will have perished, while mortality in the control group will be very low or nil.

(ii) Effect of molluscicide on "normal" snail host populations

If caged snails are not used, bioassay of the effectiveness of mollusciciding can be undertaken with reasonable statistical reliability by measuring the population density of living snails collected in a selected area (one favourable for the snail hosts) in a unit period of time just before and preferably within a week after treatment. Obviously it is important to distinguish between living and dead snails; sometimes this is not immediately apparent. Any standardized collecting method can be used, but the preferred tool in aquatic habitats involves the use of a long-handled sieve or scoop (see Annex 8). Hand-picking with forceps can be used for amphibious snails on moist-soil habitats. One or more collectors then search for snails in the selected areas(s) for a standardized period of time which may be, for example, 10 or 20 minutes per collector. The length of this period depends upon the snail density. The collections of different collectors should preferably be kept and recorded separately. The measure of snail density is the number of snails collected per person per minute. When a collection is repeated in the sample area the same collector and sieve should be used, and the collector should attempt to collect in exactly the same manner as that used in the first collections. The time interval used can be extended if the population density is low. It is better to estimate the snail density by this method in several relatively small areas than in a single large one. This method, like all the others, greatly depends for reliability on the care and accuracy of the collector, who must take particular care to avoid the temptation to increase the number of snails collected by seeking out and collecting longer in areas of greater snail density or greater accessibility of snails. The method has the advantage of being suited to almost every type of habitat and is moreover relatively simple, requires only simple tools, and facilitates reasonably accurate and useful snail population estimates in a rather short time.

During the pre-mollusciciding snail collections the risk of exposure to *Schistosoma* cercariae should, of course, be avoided.

6. FUTURE ROLE OF MOLLUSCICIDES IN SCHISTOSOMIASIS CONTROL STRATEGY

While the future status of mollusciciding in schistosomiasis control will depend on the type of control strategy adopted, which in turn, will be determined by the local ecological and socio-economic conditions, there is general agreement that judicious mollusciciding must be included in any comprehensive schistosomiasis control programme. Moreover, in certain situations the control of the snail hosts alone can confer substantial protection, although it is seldom that any single control procedure can be advocated unreservedly.

In the foreseeable future, population-based chemotherapy together with health education and focal/seasonal mollusciciding are most likely to spearhead schistosomiasis control operations in endemic foci that merit high priority. As eradication of the snail hosts is seldom a realistic goal and as the planorbids (but not the hydrobiids) have a very high intrinsic rate of natural increase, the application of molluscicides must be carefully planned to take advantage of focal and seasonal patterns of transmission; in particular, sustained efforts, demanding efficient management, well-trained and motivated staff, and a recurrent budget sufficient to fund all essential supplies and activities, will be mandatory (Annex 1).

In the future, better strategies and delivery systems will be needed to improve the cost-effectiveness of mollusciciding. For example, there is need to investigate potential new formulations of the available compounds, such as slow-release and bait mechanisms, and to explore the development of vegetable

[d] About 5 adult snails placed in a cylindrical nylon gauze cage (length 15–20 cm, diameter 5–7 cm, weighted with a small stone) staked in position and submerged in the water is recommended.

molluscicides in the endemic countries, if adequate local production can be ensured and if toxicity is not in doubt. In addition, it is now necessary, in a wide variety of socio-economic situations, to explore carefully the role as well as the efficiency of primary health care personnel and the local community in the periodic application of molluscicides, bearing in mind that staff emoluments and logistic charges are by far the most expensive components of institutionally supported focal and seasonal mollusciciding operations.

In conclusion, it is necessary once more to draw attention to the shortage of all cadres of personnel (medical, scientific and auxiliary) with suitable training and experience of schistosomiasis transmission and control, including all aspects of the application of molluscicides. Until this gap is filled the fear must remain that schistosomiasis will continue to advance, rather than recede, in distribution and intensity in most areas (in particular, in many Sub-Saharan African countries) where the infection is actually or potentially endemic. The World Health Organization has undertaken in recent years a number of training courses in close liaison with interested national authorities; more will be needed in the future.

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ANNEX 1

BASIC REQUIREMENTS FOR SUCCESSFUL PROGRAMME MANAGEMENT

Specific, preferably quantifiable objectives, relevant to both national and local levels and agreed by policy-makers and implementors, must be established.

A cost-effective technological package, proven in pilot schemes, must be available and put to maximum use.

Imaginative, well trained and committed leadership, backed by enlightened, vigorous policy-makers, is mandatory; without them the programme will be less than successful or worse it will fail utterly.

Demand for the programme must be based on justifiable health priority ratings; the views of the consumers must be constantly sought.

Intersectoral collaboration, if essential, must function not just as an ideal, but as a reality. The same is true of community involvement.

The programme should be phased realistically over space and time; over-ambition, timidity and rigidity are, among others, the ingredients of failure.

The programme in terms of needs, implementation, quality control and evaluation must be fully described in a Plan of Action which should be updated, not simply on a regular basis, but as required.

Full commitment to the continuous success of the programme by all staff members is vital and must be constantly fostered by all available means including training, incentives, inter-personal relationships, discipline, etc. Staff, who are dissatisfied without just cause, should be transferred or dismissed with least delay in case "the contamination" spreads.

Good refresher training, staff selection, supervision and simple reporting can compensate in many areas, for the lack of advanced qualifications. The latter, particularly in certain remote field conditions, may even be retrograde.

Reporting and evaluation procedures should be simplified and minimized with only critical information being monitored. Like cancer, bureaucracy must be diagnosed early and kept at bay.

Debate over the comparative efficacy of "vertical" and "horizontal" programmes is essentially invalid and wasteful as they are, if properly executed, complementary rather than incompatible.

ANNEX 2

POTENTIAL TRANSMISSION SITE SURVEY RECORD FORM

The form and the explanation appearing on the next two pages were developed by the Division of Control of Tropical Diseases, WHO.

FORM I

POTENTIAL TRANSMISSION SITE SURVEY RECORD

District ______________ **Village** ______________ **Date** ______________

Site Number		*Activities*					*Access*		*Water*			*Snails*		*Contam*		*User*		*Aid*		*Rank*	
		1	2	3	4	5	1	2	1	2	3	1	2	1	2	1	2	1	2	1	2
		Fording Collecting	Washing—Cattle Clothes—Dishes	Fishing	Ablution Bathing	Swimmint	No Access Paths	Access Paths	Fast Flow	Slow Flow	Stangant	Snail Hosts Not Found	Snail Hosts Found	Contamination Absent	Contamination Present	Users Not Infected	Users Infected	Community Aid — No	Community Aid — Yes	Transmission Rank (total)	

EXPLANATION FOR POTENTIAL TRANSMISSION SITE SURVEY RECORD

1. ACTIVITIES:

The main activity taking place at the site is recorded. If more than one activity is of major importance, then both activities may be recorded.

2. ACCESS:

The presence of a well-defined access path indicates that the site is frequently used. The absence of access paths, or a little used one, indicates that the site is rarely or not used and that transmission is low or nil.

3. WATER:

The rate and constancy of water-flow is related to the risk of transmission. Constant fast-flowing water, in general, is associated with a low risk of transmission. Similarly, most snail hosts can seldom survive in sites which dry up for five or more months each year.

4. SNAILS:

The presence or absence of snail hosts should be recorded. A 15 minute search, per person, of the places preferred by the snail hosts, in or near the site, is considered minimal.

5. CONTAMINATION:

The presence or absence of signs of urination and defecation is to be recorded. Swimming, for example, can be accepted to mean that urination takes place at that site.

6. USER:

The team should ask if the children who use the site have or have had haematuria. If infected persons use a site, which is suitable for snail hosts, this is highly significant.

7. COMMUNITY AID:

Note is made on whether the community is willing or not to help in cleaning up the contact site, in changing human behaviour by local legislation, or in doing the mollusciciding.

7. RANK:

The rank number will be the total of the coded numbers given to each category for each site, This number will ultimately determine the mollusciding/snail control procedures.

ANNEX 3

MAJOR CHARACTERISTICS OF BAYLUSCIDE®[1]

Active ingredients	Niclosamide 2'5 dichloro-4'-nitro-salicylanilide ethanolamine salt
Physical properties	
Form of technical material	crystalline solid
Solubility in water	230 mg/l (pH dependent)
Toxicity[2]	
Snail LC_{90}(mg/1×h)	3 - 8
Snail eggs LC_{90}(mg/1×h)	2 - 4
Cercariae LC_{90}(mg/1)	0.3
Fish LC_{90} (mg/1)	0.05 - 0.3
Rats, acute oral, LD_{50} (mg/kg)	5,000
Herbicidal activity	none
Stability (affected by)	
U.V. light	no
Mud, turbidity	yes
pH	optimum 6 - 8
Algae, plants	no
Storage	no
Handling qualities	
Safe	yes
Simple	yes
Formulations	70% WP 25% EC
Field dosage	
Aquatic snails (mg/1×h)	4 - 8
Amphibious snails on moist soil(g/m2)	0.2

1 Source: Schistosomiasis Control. Report of a WHO Expert Committee. *Wld. Hlth Org Tech Rep Ser,* 1973, No. 515. Bayluscide® is manufactured by Bayer AG, Sparte Pflanzenschutz, Anwendungstechnik, Beratung, 5090 Leverkusen, Bayerwerk, Germany.

2 The term mg/l×h indicates that the figures given are the product of the concentration and the number of hours of exposure.

ANNEX 4

GUIDELINES FOR MOLLUSCICIDING OPERATIONS USING NICLOSAMIDE (BAYLUSCIDE®)

1. Niclosamide (Bayluscide®) and its properties

The major characteristics of Bayluscide® are given in Annex 3 and also in Section 3.3, "Currently available molluscicides".

The active molluscicidal ingredient (a.i.) in Bayluscide® is niclosamide. Bayluscide® is a product specially developed for the destruction of freshwater snails which transmit schistosomiasis and some other trematode infections. This molluscicide can kill both the snails and their egg masses at very low concentrations (ppm or $mg.l^{-1}$) within a few hours; at such levels Bayluscide® can also kill miracidia and cercariae, the larval stages of schistosomes which may occur in the transmission foci.

Niclosamide is available in two formulations:

(i) Bayluscide® wettable powder (WP) with 70% efficiency (a.i. 70%) and

(ii) Bayluscide® emulsifiable concentrate (EC) with 25% efficiency (a.i. 25%). This product is sometimes called Clonitralide®.

As a general rule, Bayluscide® WP should be mixed at not less than 1:20 (WT/Vol.) in water and the EC formulation should be diluted to at least 1:15 (Vol./Vol.) in spraying equipment in order to facilitate improved dispersion.

Further practical information on the application of Bayluscide® is given in the following two documents which may be sent to the reader by request to the address given for each:

(i) "Bayluscide® molluscicide for the control of freshwater snails, vectors of bilharziasis" (7 pages, in English and French). Bayer AG Technical Document, Bayluscide, Sparte Pflanzenschutz, Anwendungstecknik, Beratung, 5090 Leverkusen, Bayerwerk, Germany.

(ii) *Bilharzia. A Manual for Health Workers in Malawi* 64 pages. 3rd Edition, 1986. Published with support from CIBA GEIGY Ltd. on behalf of the Ministry of Health, Lilongwe, Malawi, for the National Bilharzia Control Programme.

2. Application of niclosamide

Cost-effective mollusciciding operations require that as far as possible the correct dosage is applied; either too much or too little molluscicide is wasteful and inefficient. The correct dose (D) is derived from the product of the concentration (C) of the chemical in the waterbody and the time (T) during which the snail hosts are exposed: thus

$$D = C \times T \quad \text{and hence } C = \frac{D}{T}$$

In most field situations the dose recommended for niclosamide (see Annex 3) can be accepted as satisfactory, but in certain transmission sites it may be necessary to increase it slightly or, for example, to use the 25% E.C. formulation mixed with diesel oil, instead of the 70% W.P., in order to achieve better dispersion of the molluscicide in waterbodies where the aquatic vegetation is exceptionally dense. Niclosamide is highly toxic to the snail hosts at a concentration of 0.5 parts per million (0.5 $mg.l^{-1}$) if the water volume to be treated is accurately measured and the exposure time is 24 hours.

In transmission sites with stationary water (ponds, borrow–pits, small dams and reservoirs, etc.) the first procedure is to obtain a reasonably accurate estimation of the volume of water in cubic metres. While a satisfactory estimation of the surface area can usually be quickly obtained, measurements to determine the average depth are more time–consuming and they may need, particularly in larger waterbodies, to take account of considerable variations in depth. Inaccurate measurements of the volume of water in snail habitats larger, for example, than 10.000 m^3 can be both costly and wasteful. In fact, at the present time, mollusciciding operations in very large waterbodies are limited to specific transmission sites.

The following description of the application of Bayluscide, given in the document entitled *Bilharzia: A Manual for Health Workers in Malawi* (Anon., 1986), is exemplary.

Static water habitats

The makers of Bayluscide recommend that it should be mixed in the proportion of 1 gramme of active ingredient to two million parts (cubic centimeters) of water. This is the same as half a gramme to one million parts of water, or 0.5 parts per million (ppm). In practice, because only 70% of the powder contains the active chemical this must be allowed for when calculating the amount of chemical needed. Knowing these facts, (which never change), the only thing we have to measure when treating static water is the amount of water to treat, i.e., the volume. This is calculated by measuring the average length by the average width by the average depth (all in metres), thus:

$$Volume\,(m^3) = length \times width \times depth$$

When the volume is known the amount of chemical necessary if treating with Bayluscide 70% wettable powder is:

$$Volume\ of\ waterbody \times 0.5 \times \frac{100}{70} g$$

Or if using Bayluscide 25% emulsifiable concentrate, the amount of chemical needed is:

$$Volume\ of\ waterbody \times 0.5 \times \frac{100}{25} cm^3$$

Example

A swamp with bilharzia has an average length of 100 metres, an average width of 40 metres, and an average depth of 3/4 of a metre. How much chemical is needed to treat it? From the equation above, and using Bayluscide 70% WP, amount of chemical needed =

$$(100 \times 40 \times 0.75) \times 0.5 \times \frac{100}{70} = 2142.86 g\ or\ 2.14 kg$$

Using Bayluscide 25% EC, amount of chemical needed =

$$(100 \times 40 \times 0.75) \times .05 \times \frac{100}{25} = 6000 cm^3$$

In locations where water is static, such as swamps, dams and ponds, treatment is best carried out using sprayers. These are also useful in flowing–water habitats where vegetation obstructs the flow or in drains where the flow is so sluggish that the molluscicide will travel only a short distance before becoming ineffective. Because drains are generally of varying cross-section, and the depth of water in them can range from almost nothing to shallow ponds, it is difficult to estimate accurately the amount of chemical required to treat them effectively. For this reason it is better to overdose than underdose. For places where the flow is very slow, 30 mg Bayluscide in 10 litres of water sprayed generously over the whole surface of the water should be sufficient. The powder is placed in the sprayer with about 1 litre of water and thoroughly shaken before the remainder of the water is added. Spraying should be carried out systematically, and the entire surface of the water should be treated.

Where drains are difficult to treat because of large volumes of water, or vegetation makes access to them impossible, they can be treated by the "dam and flush" technique. This involves damming the drain at suitable points (e.g. a road bridge), and then treating the trapped water heavily (10 ppm) by blanket spraying the surface. The water is left for two hours while the water upstream is treated in the normal way (moving from mouth to source), and the dam is then breached and the entire drain flushed. This method saves chemical and has a longer-lasting effect.

For large dams and lakes, where the water is deep and there is a submerged vegetation, only the edges need be sprayed for a distance of about 5 metres from the shore. This is often best carried out from a boat.

However, as already mentioned, it is very important to remember the reservations concerning the cost-effectiveness of carrying out mollusciciding in large waterbodies. If chemical treatment does seem to be desirable it is probably best restricted to actual transmission sites where infected snails, cercariae and miracidia are concentrated, often only seasonally.

At foci, where mollusciciding:
is beyond the range of knapsack sprayers, stirrup pumps can be used. When these are unobtainable, old maize cobs soaked in a concentrated solution of Bayluscide for a week and thrown into the middle of the pond are effective.

Knapsack sprayers, as their name implies, are carried on the back of the worker, and there are models where the chemical can be pumped out by hand, while others dispense the chemical under pressure. Stirrup pumps are designed to enable the chemical to be dispensed under high pressure so that it can be projected long distances.

<u>Flowing water habitats</u>

In general the cost of mollusciciding in flowing waterbodies is more expensive than in comparable stationary transmission sites.

Chemical control of flowing water is commonly carried out by drip-feed technique. This involves the steady introduction of the chemical for a number of hours into flowing water at the source of the system. The aim is to use the flow of the water to carry the chemical throughout the system. It requires that sufficient chemical is introduced at the source to ensure that by the time the chemical front reaches the end of the scheme it is still of high enough concentration to kill the snails and their eggs. In practice the water seldom flows uninterrupted from one end of the scheme to another. There may be ponds or storage dams midway to break the flow, or in irrigation schemes there may be "dead ends" of canals, where no flow occurs unless water is being drawn from them. These factors should be taken into account and allowed for when applying mollusciciding by drip-feed. Such situations may require booster dispensers at intermediary dams, and knapsack spraying of the tail ends of static water canals, or isolated stagnant pools in natural water bodies. These places are usually primary transmission points. Dispensers (see Fig. below) should be set up at narrow or turbulent points in a stream canal to ensure complete mixing of the chemical with the water.

Chemical introduced into flowing water will be immediately carried away from the point of application, and therefore must be applied for a period of time to compensate for this. If not, it will not be in contact with any snails present long enough to kill them. The recommended time that flowing water should be treated with Bayluscide at a concentration of 1 ppm is 8 hours. The only measurement that concerns us in this situation is how fast the stream or river is flowing. This can be measured using a flow metre. However, such instruments may not be easy to obtain, and for the purposes of snail control the following procedure to measure the rate of flow or discharge is quite adequate:

(i) Measure and mark off a 20 metre stretch of the river or canal below the point where you will introduce the chemical.

(ii) Drop in a float (green twig or float) above the first mark and measure the time in seconds that it takes for the float to travel the distance between the two marks.

(iii) Repeat the operation six times and note the fastest speed.

(iv) Measure the cross-sectional area of the canal/stream. This is obtained by measuring the average width and depth, and multiplying by 0.85. The latter figure is a constant as the average flow velocity amounts to about 85% of the maximum velocity measured.

Now the Discharge (D) = speed × cross section × 0.85 m^3/sec.

Knowing the discharge, the amount of chemical (Bayluscide 70% WP) needed to treat a flowing water habitat is

$$D \times 1 \times \frac{100}{70} \textit{grams per second}$$

We have decided to treat for 6 hours (rather than 8 hours) and therefore the amount of chemical needed is

$$D \times 1 \times \frac{100}{70} \times 6 \times 60 \times 60 \ g$$

<u>Example</u>

A stream is found to have a discharge of 6 m^3/sec. How much Bayluscide 70% WP is needed to treat it?

From the equation above, the amount of chemical needed =

$$6 \times 1 \times \frac{100}{70} \times 6 \times 60 \times 60 = 185.14 \ kg$$

A convenient dispenser is a 200 litre drum that can be set to empty its contents every 30 minutes. Thus, to discharge the full amount of chemical, the drum will need to be emptied 12 times (12 × 30 mins = 6 hours). Therefore the amount of chemical that should be mixed at each filing of Bayluscide 70% WP should be:

This amount of chemical is measured out, preferably in the laboratory beforehand and stored in 12 bags of 15.42 kg each, and added to the drum when 1/4 full of water.

(ANNEX 4)

$$\frac{185}{12} = 15.42\,kg$$

When the powder has been thoroughly mixed, the remainder of the water is added, and the drum is ready for discharging. It is obvious that no break in the discharge should occur once the drip-feed has started or some water will pass by untreated. To avoid this two dispensers should be used side by side, the one being recharged while the other is discharging. Frequent stirring of the contents of the drum during discharge is also recommended to avoid the chemical settling out.

With regard to mixing the spray, the manufacturer (Bayer) recommends that Bayluscide 70% is sprayed at 1% (1 kg/100 litres water). The spray mixture should be constantly agitated. While mixing the spray it is advisable to wear a mask. For the application of Bayluscide 25% EC a dilution with water in a ratio of 1:10 to 1:60 is recommended, the latter being optimal. Bayluscide 25% EC displays an excellent spreading effect when used in combination with diesel oil at a ratio of 8.5 parts of Bayluscide 25% EC to 1.5 parts of diesel oil (see the document entitled "Bayluscide®. Molluscicide for the control of freshwater snails, vectors of bilharziasis", published by Bayer.

In some irrigation schemes it may be possible to hold the treated water in the canals/drains/dams for a period of time to allow the chemical longer contact with the snails. In order to do this we need to know the discharge of the pump or weir and the time it takes to fill the system with Bayluscide-treated water. The method for measuring the discharge is described above. The time it takes to fill the system will depend on the size of the pump/weir feeding it, and it can be calculated thus:

$$\textit{Time required to fill system} = \frac{\textit{Size of dam } (m^3)}{\textit{Capacity of pump } (m^3 \textit{ per second})}$$

Example

Size of dam and canals = 70,000 m^3. Capacity of pump = 6 m^3/sec. Therefore, time to fill the system =

$$\frac{70\,000}{6 x 3600} = 3.24\ hours = 3\tfrac{1}{4}\ hours$$

If the volume of water in the system is unknown the time taken to fill it can be calculated by first emptying the canals/dams and then measuring how long it takes for them to be filled up again. With this information it is possible to calculate the amount of chemical required as described above.

The following procedure should be adopted when carrying out a drip-feed by the above method:

(i) Inform irrigation and agricultural personnel well in advance to ensure that the day chosen for the drip-feed will suit their programme.

(ii) The day before drip-feeding switch off the pumps, (close the weir), and open the gates to the fields to reduce the level of the water in the canals as much as possible. This will reduce the amount of untreated water already present, and ensure more thorough penetration of the chemical subsequently.

(iii) On the day of the drip-feed close all the outlet gates, and switch on the pumps and the drip-feed together.

(ANNEX 4)

(iv) When the system is full switch off both pumps and dispensers and hold the water in the canals/dams for a further 24 hours before releasing it. During this time any parts where the treated water is unlikely to reach should be treated using knapsack sprayers.

(ANNEX 4)

TABLE 1: QUANTITY OF BAYLUSCIDE WP 70% NEEDED TO GIVE A CONCENTRATION OF 1 PPM IN STATIONARY WATER

VOLUME OF WATER IN CUBIC METRES	QUANTITY OF BAYLUSCIDE WP 70% NEEDED				
1	0.00143	kilograms	OR	1.43	grams[1]
2	0.00286	"	"	2.86	"
3	0.00429	"	"	4.29	"
4	0.00572	"	"	5.72	"
5	0.00715	"	"	7.15	"
6	0.00856	"	"	8.56	"
7	0.01001	"	"	10.01	"
8	0.01144	"	"	11.44	"
9	0.01287	"	"	12.87	"
10	0.01430	"	"	14.30	"
20	0.0286	"	"	28.6	"
30	0.0429	"	"	42.9	"
40	0.0572	"	"	57.2	"
50	0.0715	"	"	71.5	"
60	0.0856	"	"	85.6	"
70	0.1001	"	"	100.1	"
80	0.1144	"	"	114.4	"
90	0.1287	"	"	128.7	"
100	0.143	"	"	143.0	"
200	0.286	"	"	286.0	"
300	0.429	"	"	429.0	"
400	0.572	"	"	572.0	"
500	0.715	"	"	715.0	"
600	0.856	"	"	856.0	"
700	1.001	"			
800	1.144	"			
900	1.287	"			
1000	1.430	"			

NOTE: The efficiency of Bayluscide wettable powder is 70%. This means that to provide 1 gram of <u>active</u> Bayluscide, 1.43 g of the Bayluscide <u>powder</u> is needed.

1 In field situations, the molluscicide will be measured to the nearest gram.

TABLE 2: QUANTITY OF BAYLUSCIDE WP 70% NEEDED TO GIVE A CONCENTRATION OF 1 PPM IN FLOWING WATER

1 cubic metre = 1000 litres

DISCHARGE IN CUBIC METRES PER SECOND	PERIOD OF CONTINUOUS APPLICATION	QUANTITY OF BAYLUSCIDE WP NEEDED
0.01 (or 10 litres)	8 hours	0.4116 kg (or 411.6 g)
0.02 (" 20 ")	" "	0.8232 kg (or 823.2 g)
0.03 (" 30 ")	" "	1.235 kg
0.04 (" 40 ")	" "	1.641 kg
0.05 (" 50 ")	" "	2.058 kg
0.06 (" 60 ")	" "	2.470 kg
0.07 (" 70 ")	" "	2.882 kg
0.08 (" 80 ")	" "	3.293 kg
0.09 (" 90 ")	" "	3.705 kg
0.10 (" 100 ")	" "	4.116 kg
0.20 (" 200 ")	" "	8.232 kg
0.30 (" 300 ")	" "	12.348 kg
0.40 (" 400 ")	" "	16.464 kg
0.50 (" 500 ")	" "	20.580 kg
0.60 (" 600 ")	" "	24.696 kg
0.70 (" 700 ")	" "	28.812 kg
0.80 (" 800 ")	" "	32.928 kg
0.90 (" 900 ")	" "	37.044 kg
1.00 (" 1000 ")	" "	41.160 kg
2 CUBIC METRES	" "	82.320 kg
3 " "	" "	123.480 kg
4 " "	" "	164.640 kg
5 " "	" "	205.800 kg
6 " "	" "	246.960 kg
7 " "	" "	288.120 kg
8 " "	" "	329.280 kg
9 " "	" "	370.440 kg
10 " "	" "	411.600 kg

NOTE: The efficiency of Bayluscide wettable powder is 70%. This means that one part of the powder contains only 0.7 part of active Bayluscide. In other words, to get a concentration of 1 ppm of active Bayluscide in the water, 1.43 grams of Bayluscide WP must be applied to every cubic metre of water.

(ANNEX 4)

TABLE 3: QUANTITY OF BAYLUSCIDE EC 25% NEEDED TO GIVE A CONCENTRATION OF 1 PPM IN STATIONARY WATERS (PONDS AND POOLS, ETC.)

VOLUME OF WATER IN CUBIC METRES	QUANTITY OF BAYLUSCIDE NEEDED			
1	0.004	kilograms	OR	4 grams
2	0.008	"	"	8 "
3	0.012	"	"	12 "
4	0.016	"	"	16 "
5	0.020	"	"	20 "
6	0.024	"	"	24 "
7	0.028	"	"	28 "
8	0.032	"	"	32 "
9	0.036	"	"	36 "
10	0.040	"	"	40 "
20	0.080	"	"	80 "
30	0.120	"	"	120 "
40	0.160	"	"	160 "
50	0.200	"	"	200 "
60	0.240	"	"	240 "
70	0.280	"	"	280 "
80	0.320	"	"	320 "
90	0.360	"	"	360 "
100	0.400	"	"	400 "
200	0.800	"	"	800 "
300	1.200	"		
400	1.600	"		
500	2.000	"		
600	2.400	"		
700	2.800	"		
800	3.200	"		
900	3.600	"		
1000	4.000	"		

NOTE: To get a concentration of 1 ppm, 4 g of the emulsifiable concentrate would be needed to treat each cubic metre of water.

(ANNEX 4)

TABLE 4: QUANTITY OF BAYLUSCIDE EC 25% NEEDED TO GIVE A CONCENTRATION OF 1 PPM IN FLOWING WATER

1 cubic metre = 1000 litres

DISCHARGE OR FLOW PER SECOND	PERIOD OF CONTINUOUS APPLICATION	QUANTITY OF BAYLUSCIDE EC 25% REQUIRED FOR ENTIRE PERIOD OF APPLICATION
0.001 cubic metres, or 1 litre	8 hours	115.2 grams
0.002 " " " 2 "	" "	230.4 "
0.003 " " " 3 "	" "	345.6 "
0.004 " " " 4 "	" "	460.8 "
0.005 " " " 5 "	" "	576.0 "
0.006 " " " 6 "	" "	691.2 "
0.007 " " " 7 "	" "	806.4 "
0.008 " " " 8 "	" "	921.6
0.009 " " " 9 "	" "	1.0368 kg
0.010 " " " 10 "	" "	1.152 "
0.020 " " " 20 "	" "	2.304 "
0.030 " " " 30 "	" "	3.456 "
0.040 " " " 40 "	" "	4.608 "
0.050 " " " 50 "	" "	5.760 "
0.060 " " " 60 "	" "	6.912 "
0.070 " " " 70 "	" "	8.064 "
0.080 " " " 80 "	" "	9.216 "
0.090 " " " 90 "	" "	10.368 "
0.100 " " " 100 "	" "	11.520 "
0.200 " " " 200 "	" "	23.040 "
0.300 " " " 300 "	" "	34.560 "
0.400 " " " 400 "	" "	46.080 "
0.500 " " " 500 "	" "	57.600 "
0.600 " " " 600 "	" "	69.120 "
0.700 " " " 700 "	" "	80.640 "
0.800 " " " 800 "	" "	92.160 "
0.900 " " " 900 "	" "	103.680 "
1.000 " "	" "	115.200 "

Fig. 6: LIQUID BISPENSER — FLOAT BOX TYPE

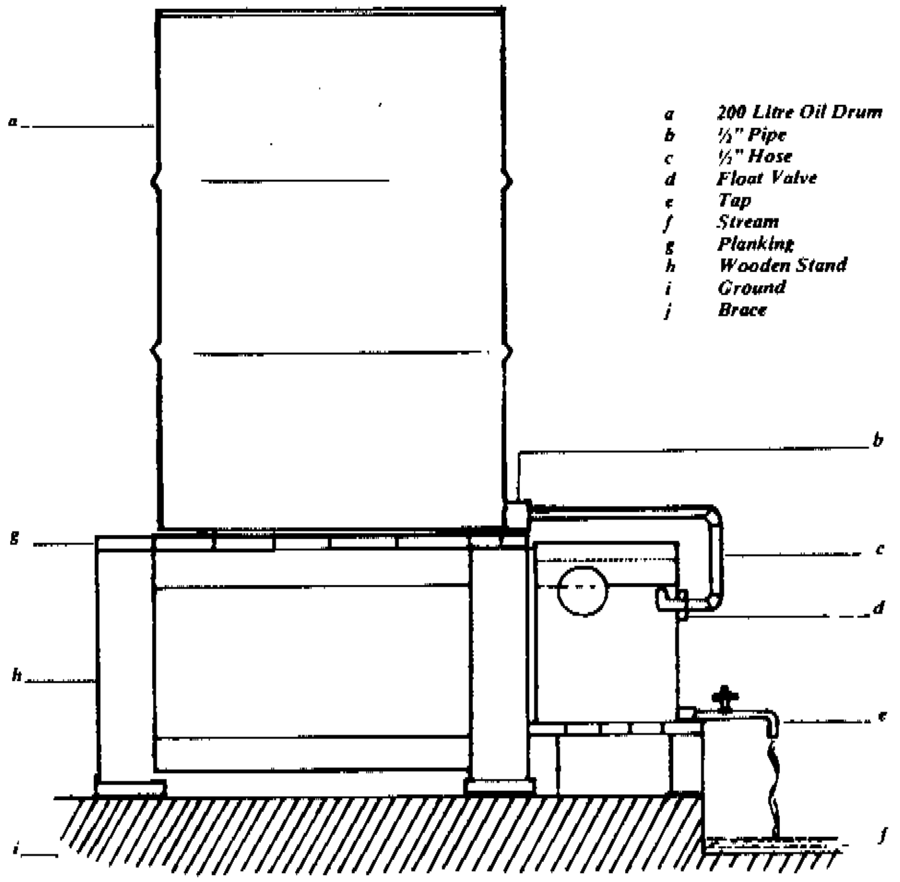
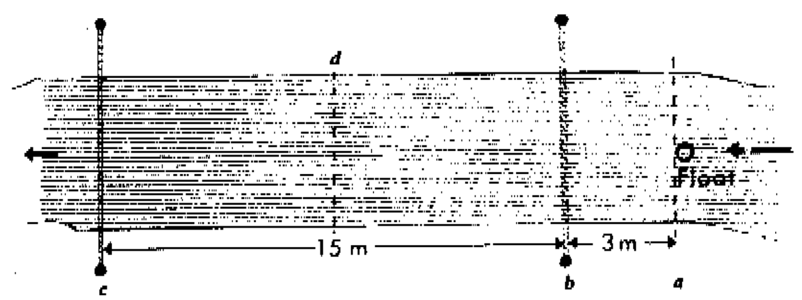


Fig. 7: EVALUATION OF DISCHARGE BY FLOAT METHOD



a Float dropped into water
b Float enters run
c End of run
d Point where cross-sectional area is measured

Source: *Bilharzia. A Manual for Health Workers in Malawi.*

(ANNEX 4)

ANNEX 5

DESIRABLE CHARACTERISTICS OF MOLLUSCICIDAL PLANTS[1]

Toxicity	High toxicity against target organisms; low or no toxicity against non-target organisms at molluscicidal concentrations.
Supply	Readily available locally.
Yield	High yield of molluscicidal material per plant and per unit area of cultivated land.
Type of plant	Perennial rather than annual; reproduce by seeds rather than by tubers; drought resistant for use in arid areas; semiacquatic or aquatic for use directly in snail habitats; high propagation and rapid growth rates with minimum capital and labour input; high adaptability to differing local environmental conditions; high resistance to pests, weeds, etc.
Plant parts	Localization of high potency levels in regenerating parts (berries, fruits, flowers, nuts, deciduous leaves) or vegetatively planted tubers.
Storage	Molluscicidal material of seasonally producing plants should not lose potency during storage of at least one year.
Extraction	Active principle should be extractable by simple apparatus and commonly available solvents, preferably water.
Physio-chemical stability	Retention of molluscicidal potency under physio-chemical influences (pH, sunlight, temperature, silt, organic matter, water pollution) normally found in the endemic area during the annual cycle.
Knowledge of plant in endemic area	A good knowledge of growing habits and requirements, toxicity and any medicinal properties of plants by local people, is an asset.
Cultural acceptability	Absence of spiritual and ceremonial uses of plants and aversions based on folklore and magic, which might interfere with their use for snail control, is desirable.
Additional uses	Suitability of the same plant parts for other public health, local, domestic or industrial uses.

1 Kloos, H. and McCullough, F.S. (1982). Plant Molluscides. *Planta Medica* 46: 193-209.

ANNEX 6

MAJOR CLASSES OF NATURAL PRODUCTS WITH RECOGNIZED MOLLUSCICIDAL ACTIVITY[1]

Class of compound	Plant	Family
Triterpenoid saponins	*Phytolacca dodecandra*	Phytolaccaceae
	Hedera helix	Araliaceae
	Lonicera nigra	Caprifoliaceae
Spirostanol saponins	*Cornus florida*	Cornaceae
	Balanites aegyptiaca	Balanitaceae
	Asparagus curillus	Liliaceae
Steroid glycoalkaloids	*Solanum mammosum*	Solanaceae
Diterpenes	*Wedelia scaberrima*	Compositae
	Baccharis trimera	Compositae
Sesquiterpenes	*Warburgia ugandensis*	Canellaceae
	Warburgia stuhlmannii	Canellaceae
	Ambrosia maritima	Compositae
	Podachaenium eminens	Compositae
Monoterpenes	*Genus Lippia*	Verbenaceae
Iridoids	*Olea europaea*	Oleaceae
Naphthoquinones	*Diospyros usambarensis*	Ebenaceae
Alkenyl phenols	*Anacardium occidentale*	Anacardiaceae
Chalcones	*Polygonum senegalense*	Polygonaceae
Flavonoids	*Baccharis trimera*	Compositae
	Polygonum senegalense	Polygonaceae
	Polygonum nodosum	Polygonaceae
Tannins	*Acacia nilotica*	Leguminosae
	Other species	
Furanocoumarins	*Ruta chalepensis*	Rutaceae
Isobutylamides	*Heliopsis longipes*	Compositae
	Fagara macrophylla	Rutaceae
Alkaloids	*Culpurnia aurea*	Leguminosae

[1] Marston, A. and Hostettman, K. (1985). Plant Molluscicides. *Phytochemistry* 24: 639–652.

ANNEX 7

SOME EQUIPMENT USED FOR MOLLUSCICIDE APPLICATION[1]

Type of habitat	Equipment suggested
Dry/moist soil areas	Watering can. Stirrup pump. Knapsack sprayer. Compression sprayer. Portable pumps: (a) manually operated (b) powered. Granule/pellet applicator.
Still water of various extents, depths and configurations.	Stirrup pump. Portable pumps, (a) manually operated. (b) powered. Knapsack sprayer. Granule/pellet applicator.
Flowing water of various extents, depths and configurations.	Solution dispensers of various types. Automatic dispenser fitted with agitator.

Note: For further information on equipment please write to Director, Division of Control of Tropical Diseases, WHO, Avenue Appia, 1211 Geneva 27, Switzerland.

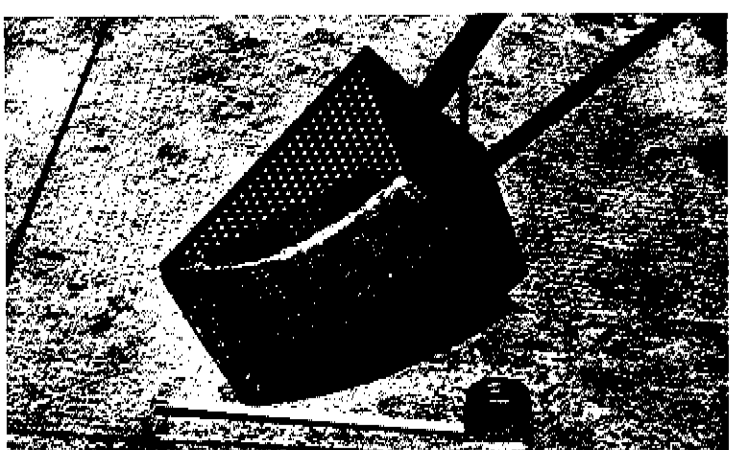
[1] After: Ansari, N., Ed. (1973). *Epidemiology and Control of Schistosomiasis (Bilharziasis)*. S. Karger, Basel, Paris, London, New York.

ANNEX 8

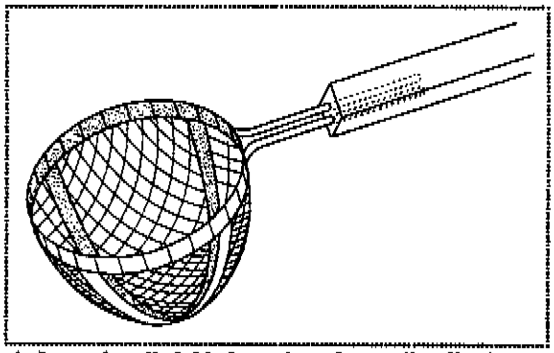
SOME SNAIL COLLECTING DEVICES USED IN FIELD SURVEYS

Many kinds of snail collecting scoops have been designed and used in different endemic countries. Some are shown below. It is not recommended to collect snail hosts by hand because of the risk of infection. If the hands or other parts of the body have been exposed to potentially contaminated water, they should be dried off immediately by brisk rubbing. The snails can be transferred from the scoops to another container by long, pliable forceps. The following extract from *Bilharzia. A Manual for Health Workers in Malawi* may be useful.

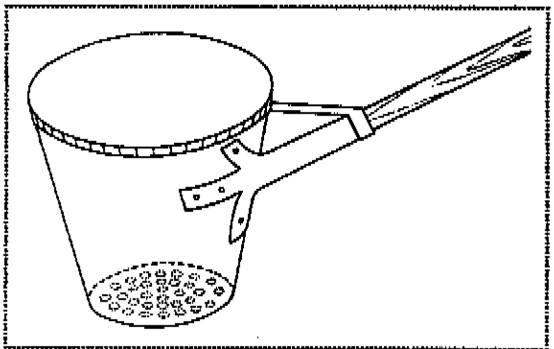
> When searching for snails it is advisable to look first without the aid of the scoop for snails that may be more easily collected with forceps. Snails are usually most abundant in vegetation, and the scoop is best placed under floating weeds and then shaken gently to dislodge the snails. Alternatively, clumps of vegetation can be removed from the water with the scoop and placed on a large tray. Vigorous shaking of the vegetation with forceps dislodges the snails on to the tray where they can be more easily seen and collected.
>
> In ponds and streams with muddy bottoms care should be taken not to scoop too deep as scoopfuls of mud hide the snails. When mud and decaying vegetation are abundant, especially in shallow water, the snails can often be more easily seen if the scoop is cleaned before inspection by moving it gently back and forth on the surface of the water so that the mud is washed away.
>
> If a search is being made along a shallow water course it is best to work from mouth to source (upstream), so that muddy or turbid water caused by scooping is carried away from the unsearched area ahead.



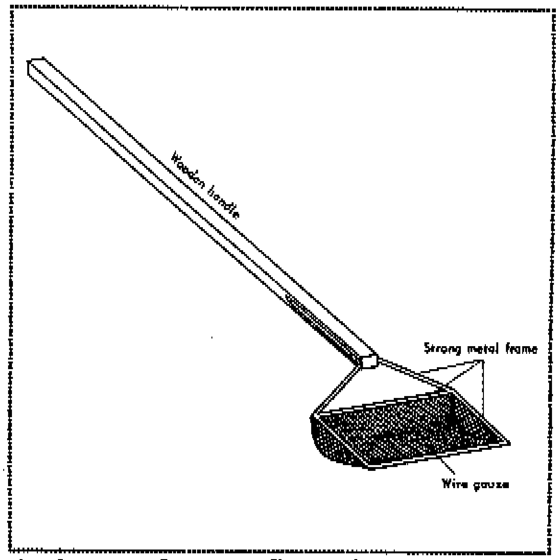
Snail-collecting scoop used in Brazil. This sturdy rectangular scoop is made of heavy-gauge perforated sheet metal with a forward cutting edge and a deep rear portion.



A. Long-handled kitchen sieve for snail collecting.

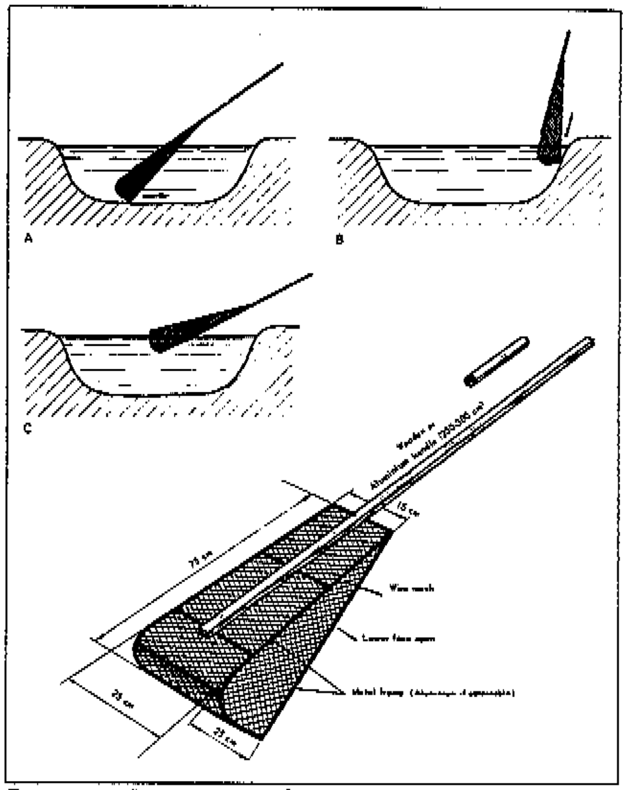


B. Snail scoop used in Brazil for snail collecting.



Another type of scoop or dip-net for snail collecting.

The drag scoop consists of a long-handled wire-mesh net with a deep belly, properly braced. The sample is taken by placing the scoop face downwards and dragging it across the bottom and up the side to the water's edge. Here the scoop is inverted and the mud is washed out. The scoop can be used to sample a finite portion of the bottom, but it is comparatively slow and laborious in operation.



Drag scoop for snail collecting
A. Start of sampling
B. End of sampling
C. Washing the sample

Source of illustrations: Ansari, N. (1973). See references.

Checking on snails after treatment.

(ANNEX 8)